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POLY-WRI 1567-89

Final Report
under
ARO Contract No. DAAL03-88-K-0119
Low Frequency Gyrotron Amplifier Investigation-Phase II
for the period
July 1, 1988 - September 15, 1989

Route 110 Farmingdale, New York 11735

Weber Research Institute

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Principal Investigator

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Abstract

The dispersion relation of a periodically disc loaded cylindrical waveguide is delivered for the H11 mode, in connection with a wide band gyro-TWA analysis. The results are shown to match accurately with the experimental results. The characteristic impedance of this cold circuit is also derived and shown to match experimental results accurately through measurements of the return loss of the circuit. The possibility of absolute instabilities is discussed.

I. INTRODUCTION:

In a recent publication [1], the feasibility of using a disc loaded circular waveguide as the circuit for a gyro-TWA to achieve high quality wideband operation was shown. The operating mode was the hybrid H_{11} mode associated with the disc loaded circuit. The field distribution of this mode near the axis is the same as that of the conventional TE_{11} mode. Hence, the use of the conventional gyrotron dispersion relation, with some minor modification, can be justified if the beam is confined near the axis. The analyses were based on using a polynomial of a higher degree than the typical hyperbola relation for a smooth waveguide to represent the circuit dispersion relation. The coeficients of the polynomial were obtained from curve fitting with the experimental measurements on the cold circuit. However, for the theoretical work to be self-contained, the dispersion relation should be based on an analysis of the boundary value problem. This is where numerical difficulties were encountered. The convergence to a solution was very sensitive to the design parameters of the circuit. In the following, we first present a different approach which yields the dispersion relation equations that overcomes this problem. This approach gives excellent agreement with the experimental results. This paper is also motivated by new data of experiments performed at ETDL. In particular with regard to the circuit reflection coeficient to which we devote a section of this paper, together with the derivation of the characteristic impedence of the gyrotron circuit. In the last section, we discuss the possibility of an absolute instability which was not explicitly discussed in [1]-[2]-[3].

II. DISPERSION RELATION OF THE COLD CIRCUIT:

The analysis of the cold circuit performed in the previous work [1] was made by solving the boundary value problem of the disc loaded waveguide geometry (Fig.1) while invoking the Floquet theorem. Fields in region I and II are expressed in terms of the fundamental modes in the respective regions. Continuity of E_ϕ, H_ϕ and E_z, H_z at the boundary r = a are forced, and a set of homogeneous equations for the modal amplitudes are obtained. For non trivial solution, the corresponding determinant must vanish. This then yields, in principle, the circuit dispersion relation for the entire Brillouin diagram. It is the solution of an infinite determinant equal to zero. The convergence to an accurate numerical solution while truncating the infinite matrix is the problem which has not been resolved in general. Instead an adhoc method was devised for the problem at hand. The method [1] was not entirely successful since the accuracy of the solution was very much dependent upon the value of the periodic length L (Fig.1): for accurate results, the value of L would not be useful for the high quality gyro-TWA applications; and conversely, for parameters suitable for high quality gyro-TWA applications, the numerical solution for the cold circuit converges poorly. In this paper we present a different approach. It was decided that the circuit is to be described as a transmission line loaded periodically by shunt suceptances. The dispersion relation of the periodic circuit is obtained from the suceptance B of a single iris with the help of the Galerkin method which provides a powerful numerical tool for a relatively fast and accurate convergence of the solution. This was demonstrated by Scharstein and

Adams [4] upon whose work, with some minor modifications, we based the first part of this paper. With reference to Fig. 2, the fields at $z = 0$ are given by:

* <u>In region I</u>, the TE_{11} is the only incident field, and all the TE_{1n} and TM_{1n} ($n = 1....\infty$) are reflected fields, i.e.,

$$\underline{E}_i = \underline{e}_1^{Ih}$$

$$\underline{H}_i = Y_1^h \underline{h}_1^{Ih}$$

$$\underline{E}_r = \Sigma_n\left\{V_n^{Ih} \underline{e}_n^{Ih} + V_n^{Ie} \underline{e}_n^{Ie}\right\}$$

$$\underline{H}_r = -\Sigma_n\left\{Y_n^{Ih} V_n^{Ih} \underline{h}_n^{Ih} + Y_n^{Ie} V_n^{Ie} \underline{h}_n^{Ie}\right\}$$

* <u>In region II</u>, all the TE_{1n} and TM_{1n} ($n = 1...\infty$) are transmitted fields, i.e.,

$$\underline{E}_t = \Sigma_n\left\{V_n^{IIh} \underline{e}_n^{IIh} + V_n^{IIe} \underline{e}_n^{IIe}\right\}$$

$$\underline{H}_t = -\Sigma_n\left\{Y_n^{IIh} V_n^{IIh} \underline{h}_n^{IIh} + Y_n^{IIe} V_n^{IIe} \underline{h}_n^{IIe}\right\}$$

where $\underline{e}$ and $\underline{h}$ are the modal vectors [5], the superscripts e and h correspond to the TM and TE components respectively, and I and II correspond to the two regions as depicted in Fig.2.

Across the aperture, $\underline{H}$ must be continuous. Making use of the facts that the two regions are identical ($\underline{e}_n^{Ih} = \underline{e}_n^{IIh} = \underline{e}_n'^{h}$, etc) and that $-\underline{z}_o \times \underline{h}_n = \underline{e}_n$, the continuity of $\underline{H}$ across the aperture at $z = 0$ can be expressed by:

$$Y_1^h \underline{e}_1'^h = \Sigma_{n=1}^{\infty}\left\{Y_n^h V_n^h \underline{e}_n'^h + Y_n^e V_n^e \underline{e}_n'^e\right\} \tag{1}$$

The electric field over the aperture is given in terms of the modal fields by:

$$\underline{E}_{ap} = \Sigma_{k=1}^{\infty}\left\{V_k^h \underline{e}_k^h + V_k^e \underline{e}_k^e\right\} \tag{2}$$

Taking the inner product of the aperture field with a modal field will yield the amplitude, viz.,

$$V_n = \langle E_{ap}, e_n \rangle = \int_S \underline{E}_{ap} \cdot \underline{e}_n \, ds \tag{3}$$

where S is the aperture cross section. Substituting (2) into (3), and the result into (1), we get:

$$Y_1^h \, \underline{e}_1'^h = \Sigma_{n=1}^{\infty} \Big\{ Y_n^h (\Sigma_k V_k^h \langle \underline{e}_k^h, \underline{e}_n'^h \rangle \underline{e}_n'^h + \Sigma_k V_k^e \langle \underline{e}_k^e, \underline{e}_n'^h \rangle \underline{e}_n'^h) + Y_n^e (\Sigma_k V_k^h \langle \underline{e}_k^h, \underline{e}_n'^e \rangle \underline{e}_n'^e + \Sigma_k V_k^e \langle \underline{e}_k^e, \underline{e}_n'^e \rangle \underline{e}_n'^e) \Big\} \tag{4}$$

where the primed quantities are associated with the aperture and the un-primed with the waveguide. We now take the inner product of (4) with the aperture mode functions, first with $\underline{e}_1'^h$ and then with $\underline{e}_1'^e$ to yield the following set of equations:

$$\begin{aligned} &\Sigma_{k=1}^{\infty} \Sigma_{n=1}^{\infty} \Big\{ (Y_n^h \langle \underline{e}_k'^h, \underline{e}_n^h \rangle \langle \underline{e}_n^h, \underline{e}_1'^h \rangle + Y_n^e \langle \underline{e}_k'^h, \underline{e}_n^e \rangle \langle \underline{e}_n^e, \underline{e}_1'^h \rangle) V_k^h + \\ &\quad (Y_n^h \langle \underline{e}_k'^e, \underline{e}_n^h \rangle \langle \underline{e}_n^h, \underline{e}_1'^h \rangle + Y_n^e \langle \underline{e}_k'^e, \underline{e}_n^e \rangle \langle \underline{e}_n^e, \underline{e}_1'^h \rangle) V_k^e \Big\} = Y_1^h \langle \underline{e}_1^h, \underline{e}_1'^h \rangle \\ &\Sigma_{k=1}^{\infty} \Sigma_{n=1}^{\infty} \Big\{ (Y_n^h \langle \underline{e}_k'^h, \underline{e}_n^h \rangle \langle \underline{e}_n^h, \underline{e}_1'^e \rangle + Y_n^e \langle \underline{e}_k'^h, \underline{e}_n^e \rangle \langle \underline{e}_n^e, \underline{e}_1'^e \rangle V_k^h + \\ &\quad (Y_n^h \langle \underline{e}_k'^e, \underline{e}_n^h \rangle \langle \underline{e}_n^h, \underline{e}_1'^e \rangle + Y_n^e \langle \underline{e}_k'^e, \underline{e}_n^e \rangle \langle \underline{e}_n^e, \underline{e}_1'^e \rangle) V_k^e \Big\} = Y_1^h \langle \underline{e}_1^h, \underline{e}_1'^e \rangle \end{aligned} \tag{5}$$

which can be written in matrix form as:

$$\begin{pmatrix} Y_{1k}^{hh} & Y_{1k}^{he} \\ Y_{1k}^{eh} & Y_{1k}^{ee} \end{pmatrix} \begin{pmatrix} V_k^h \\ V_k^e \end{pmatrix} = \begin{pmatrix} I_1^h \\ I_1^e \end{pmatrix} \tag{6}$$

where

$$I_1^h = Y_1^h \, \langle \underline{e}_1^h, \underline{e}_1'^h \rangle$$

$$I_1^e = Y_1^h \, \langle \underline{e}_1^h, \underline{e}_1'^e \rangle$$

Note that $I_1^e = 0$ since the TE_{11} mode is the only one incident. This makes the RHS of the second equation in (5) equal to zero. Solving equation (6) will yield V_1^h, the amplitude of the hybrid propagating H_{11} mode across the aperture at z = 0. This solution will be complex and must equal the incident and reflected amplitudes, i.e.,

$$V_1^h = u + jv = 1 + \Gamma$$

Since, in the first approximation

$$\Gamma = - \frac{jB}{2 + jB}$$

we finally get $B = -2v/u$.

We now have a transmission line of characteristic admittance Y_o, periodically loaded with shunt admittances $Y_s = jB$ (Fig.3). The dispersion relation of such a structure is easily derived to be:

$$j \frac{Y_s}{Y_o} \sin\beta L = 2(\cos kL - \cos\beta L)$$

that is,

$$kL = \cos^{-1}\left\{\cos\beta L - B/2 \sin\beta L\right\} \qquad (7)$$

where β is the propagation constant of the TE_{11} mode.

This whole procedure was programmed into a desktop computer, with numerical solutions obtained for various values of parameters a, b, and L, and the results compared to the experimental data. Figures 4 through 8 show the numerical and experimental plots obtained. The agreement is indeed excellent for large aperture. The slope of the dispersion curves and the range of allowed frequencies depend on the ratio a/b, and the larger this ratio, the better the agreement. The suceptance of the disc varies with frequency as could be expected: it is inductive over most of the passband, goes through a resonnant point, and becomes capacitive near the higher cut-off. The discrepancy between the results is quite small for a/b > 0.5, the maximum error anywhere being <u>less than 5%</u>, and it is largest near the cut-off points. It stems from the fact that, near the lower cut-off, the numerical suceptance is too inductive, whereas it is too capacitive near the higher cut-off point. Introducing more capacitive terms in eq.2 makes the error almost vanish near the lower cut-off point but increases it

near the higher cut-off, and vice-versa. For the model (Fig.4) used for the analysis in [1], the agreement is nearly perfect for the operating frequency band, and equal to about 1% at cut-off points. Similar accuracy is also seen for other models (Fig.5-7).

II. THE COLD CIRCUIT IMPEDANCE:

The dispersion relation obtained in the above is that of the circuit of infinite length. In the real situation of the gyro-TWA, we found in [1] the optimum length to be the equivalent of 18 periodic lengths. Of interest is of course the impedance characteristics from which the feed circuit can be designed. In the experimental set-up, the disc loaded circuit is fed through a smooth cylindrical waveguide of radius equal to b, propagating a TE_{11} mode, and loaded by the same waveguide containing a conic absorber. To describe this circuit, we find the characteristic impedance Z_c of the disc loaded circuit, based on the approach described in [6]. We then use the well known formulas of impedance transformation to find the input impedance Z_{in} at $z = 0$, hence $\Gamma(\omega)$.

Thus, starting with a unit cell (Fig.3), the characteristic impedance of a periodic structure is given by:

$$Z_c = \frac{Z_{11} - Z_{22}}{2} + Z_{12} \sinh\gamma L$$

where $\gamma = jk$ and the Z_{ij}'s are that of a unit cell. Since the cell is symmetrical, $Z_{11} = Z_{22}$, and the expression for Z_c reduces to:

$$Z_c = j\, Z_{12} \sin kL \tag{8}$$

Now, by definition of Z_{12} and a few simple algebraic manipulations, we get:

$$Z_c = \frac{\sin kL}{\frac{B}{2}(1 + \cos\beta L) + \sin\beta L} \tag{9}$$

We can now substitute eq.9 into

$$Z_{in} = Z_c \frac{Z_o \cos kl + j Z_c \sin kl}{Z_c \cos kl + j Z_o \sin kl}$$

where $l = 18L$, and the result into the expression for Γ, i.e.,

$$\Gamma = \frac{Z_{in} - Z_o}{Z_{in} + Z_o}$$

Fig.9 shows the plots of the numerical and the experimental values of Γ. The agreement is remarkable: it proves the validity of the approximation made in Section I which, not only simplifies the equations considerably, but also gives accurate results and shows all of the experimental features observed. Thus, we see that, over the range of frequencies of interest, what showed in the previous approach as a passband becomes now a series of resonnant and antiresonnant frequencies which alternate in an interference pattern. A number of fringes (or lobes) appear whose width is not constant but very narrow near both cut-offs and wider around the middle of the band. Also, the reflection is high near cut-offs as could be expected, but much lower in the passband. To eliminate reflections from both ends, the gyro circuit should be fed with a cylindrical waveguide of a different radius whose characteristic impedance is equal to Z_c of eq.9. This will insure the equality of the match through all the experimental arrangement.

III ABSOLUTE INSTABILITY IN THE GYRO-TWA:

In the previous paper [1], we discussed and showed how a particular beam mode can be chosen to interact best with the H_{11} mode of the gyro-TWA circuit: the slope of the beam mode and the electron cyclotron frequency Ω can be adjusted to achieve a reasonably flat linear gain over the whole frequency range of the first Brillouin zone. Higher gain may be achievable, but at the expense of a smaller bandwidth, and with the added risk of creating an absolute instability near the lower cut-off. This is shown by the extraordinarily high gain obtained when using real ω complex k in the linear analysis of the interaction. (Notice that this does not happen when complex ω real k is used.) This is an indication of the likelyhood of the onset of the absolute instability which appears whenever $k_c = \omega_c/c$ and $k_b = \Omega/c$ are very close. This is shown in Fig.10. Therefore, one way to deal with this problem is to separate k_c from k_b by increasing the gap between the two. However, this can be done only to a point because, one may lose the benefits derived from the use of the TWA circuit by doing so: another parameter has to be taken into account which will indeed provide for the strength and the range of the interaction. By increasing the gap between k_c and k_b, one has to decide whether to keep the slope constant. This will change the effectiveness of the interaction by changing the linear gain, the "passband", and also the flatness of the curve. It is however possible to find a beam mode which optimizes, and at the same time tunes away the absolute instability.

To verify this behavior, we also looked into the effect of decreasing the beam current. This of course will decrease the linear gain,

but the decrease will be mild since the gain is proportional to $I_b^{1/3}$ only. However, from Fig.11, the peak close to k = 0 which represents the absolute instability is dramatically damped. For a low enough value of the current, two regions appear separated by a sharp drop in the gain: one very narrow region with a large gain, the other comparable to what we had before except for a smaller bandwidth.

CONCLUSION:

We have presented in this paper a new way to derive the dispersion relation of a disk loaded cylindrical waveguide which gives very accurate results. The characteristic impedance was calculated as well as the reflection coeficient, the results comparing extremely well with the experiments. The possibility of the existence of an absolute instability is discussed, and ways to prevent its onset presented.

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FIGURE CAPTIONS

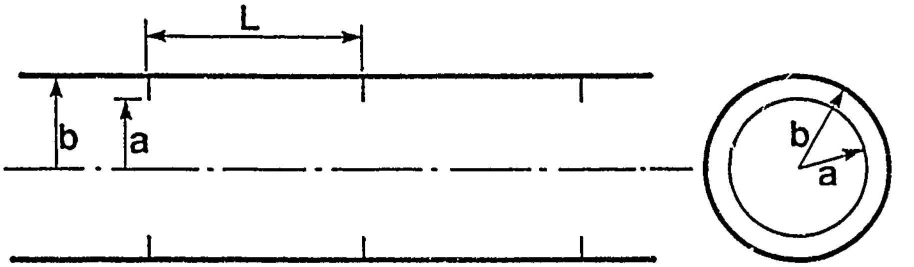


Fig.1 Geometry of the periodically disc-loaded waveguide circuit

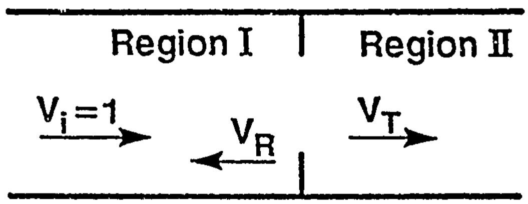


Fig.2 Waves and symbols used in the equations

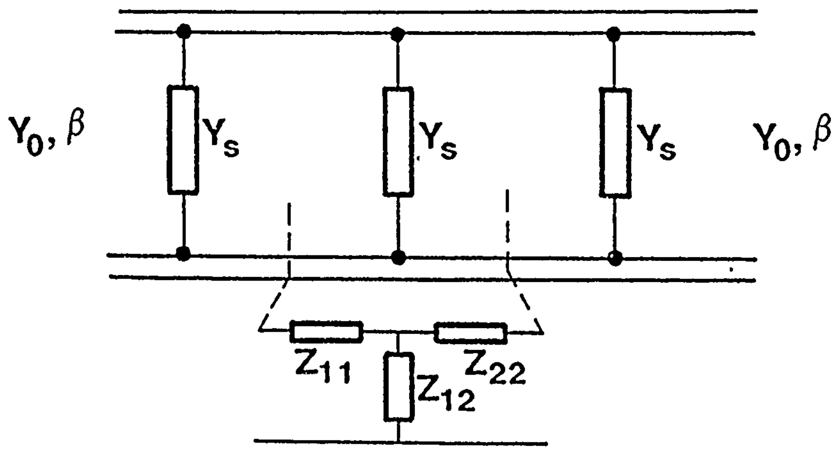


Fig.3 Periodic shunt suceptances and a unit cell

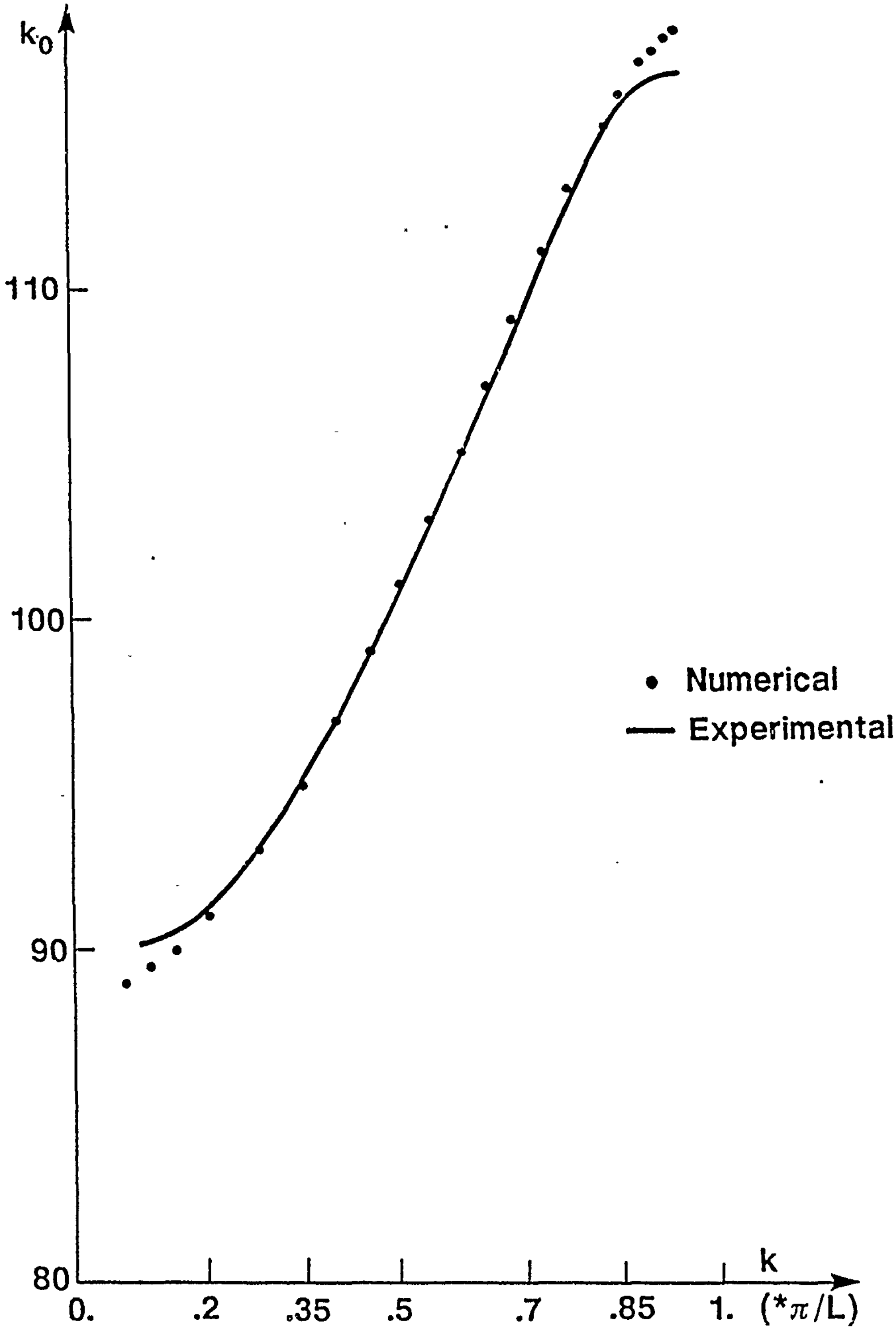


Fig.4 Dispersion relation: L=2.7cm, b=2.98cm, a/b=0.5

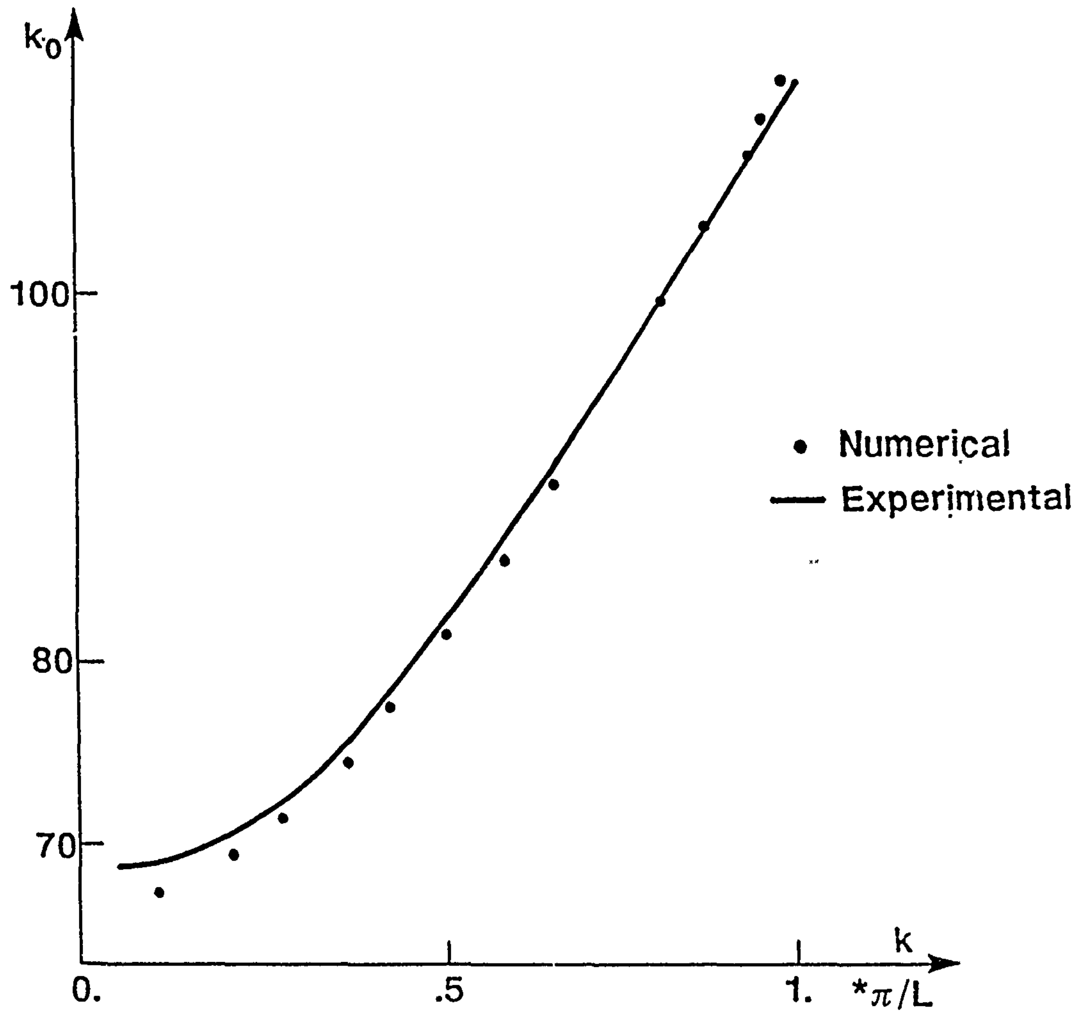


Fig.5 Dispersion relation: L=3.3cm, b=2.98cm, a/b=0.75

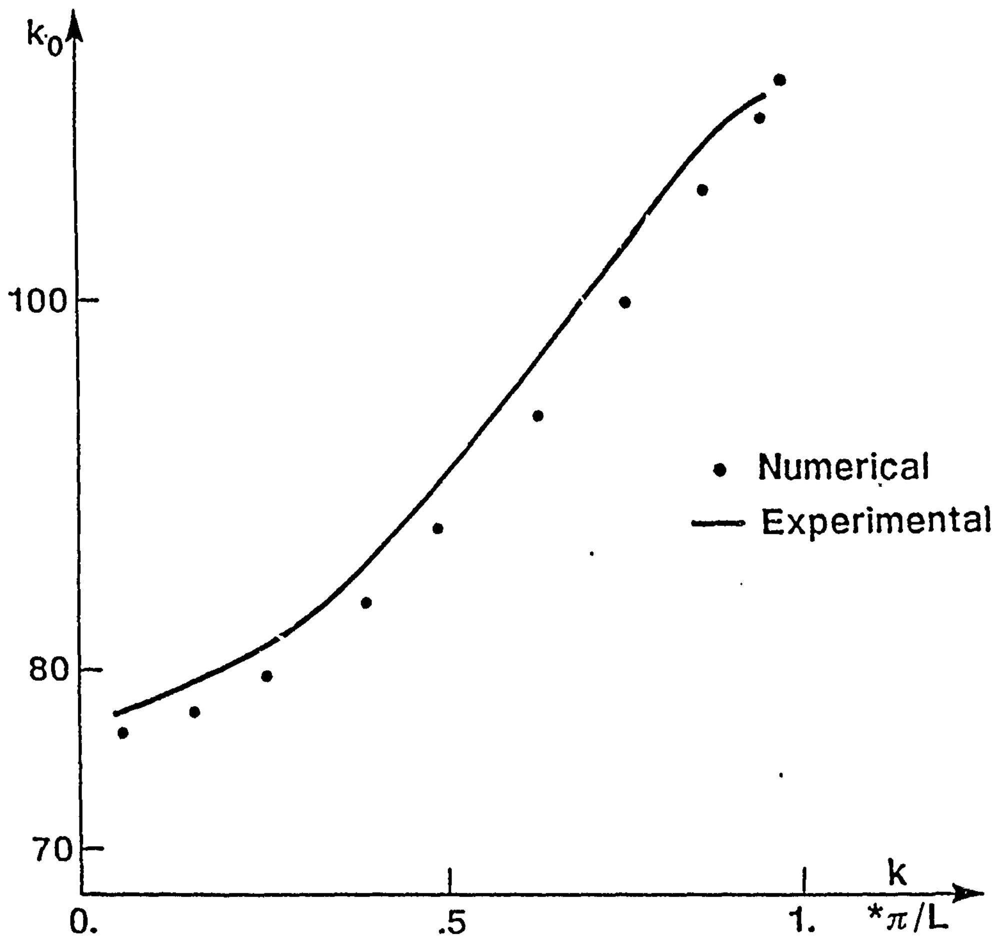


Fig.6 Dispersion relation: L=3.3cm, b=2.98cm, a/b=0.6

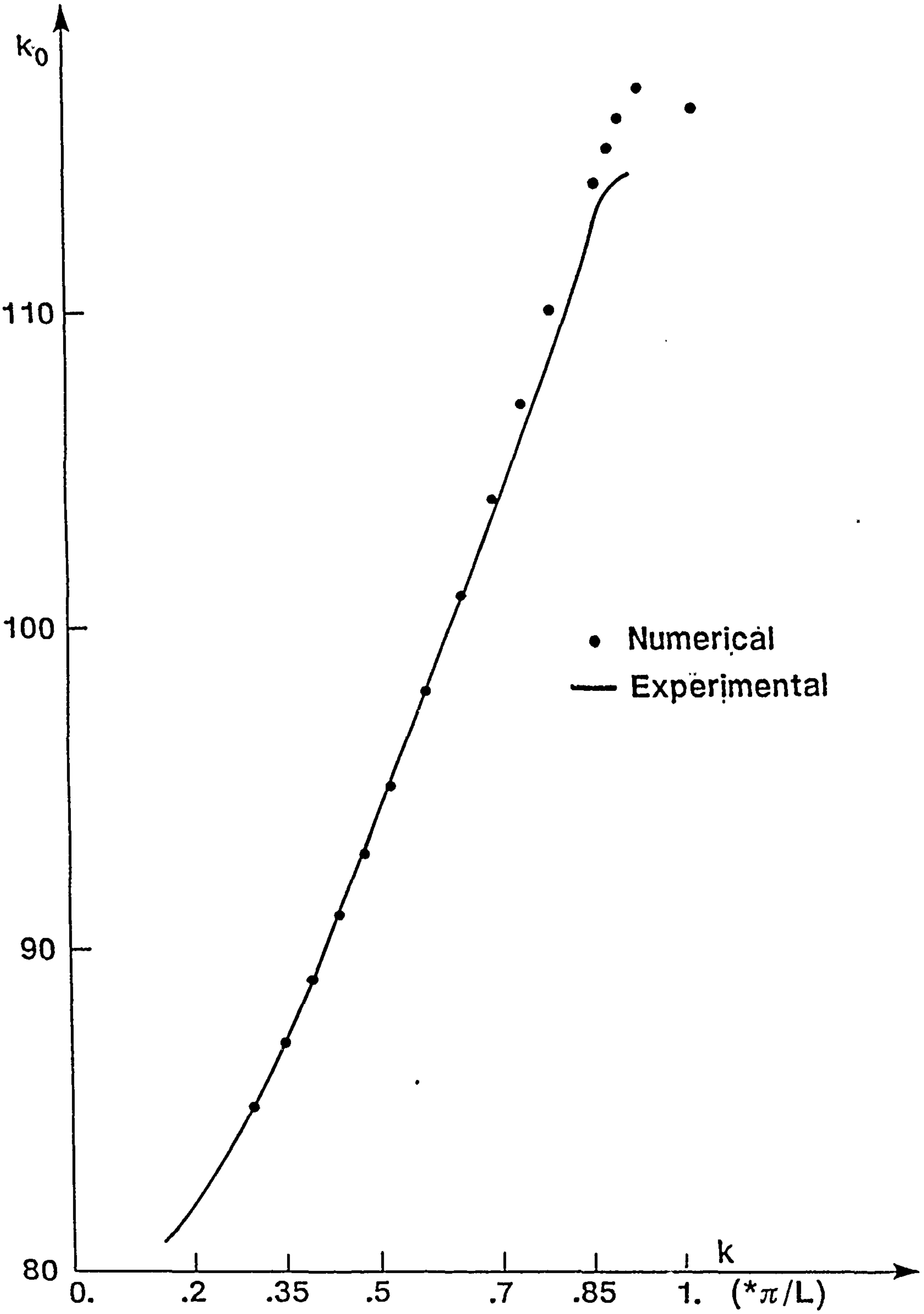


Fig.7 Dispersion relation: L=2.7cm, b=2.98cm, a/b=0.6

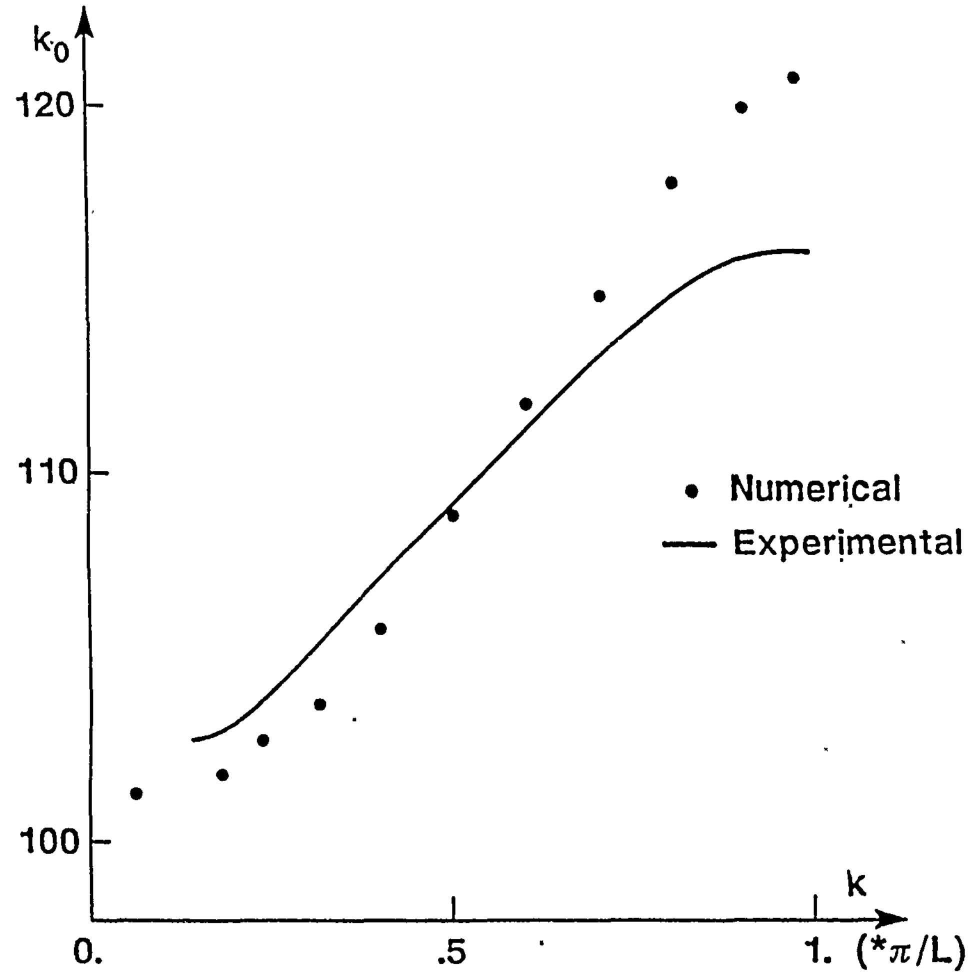


Fig.8 Dispersion relation: L=2.7cm, b=2.98cm, a/b=0.4

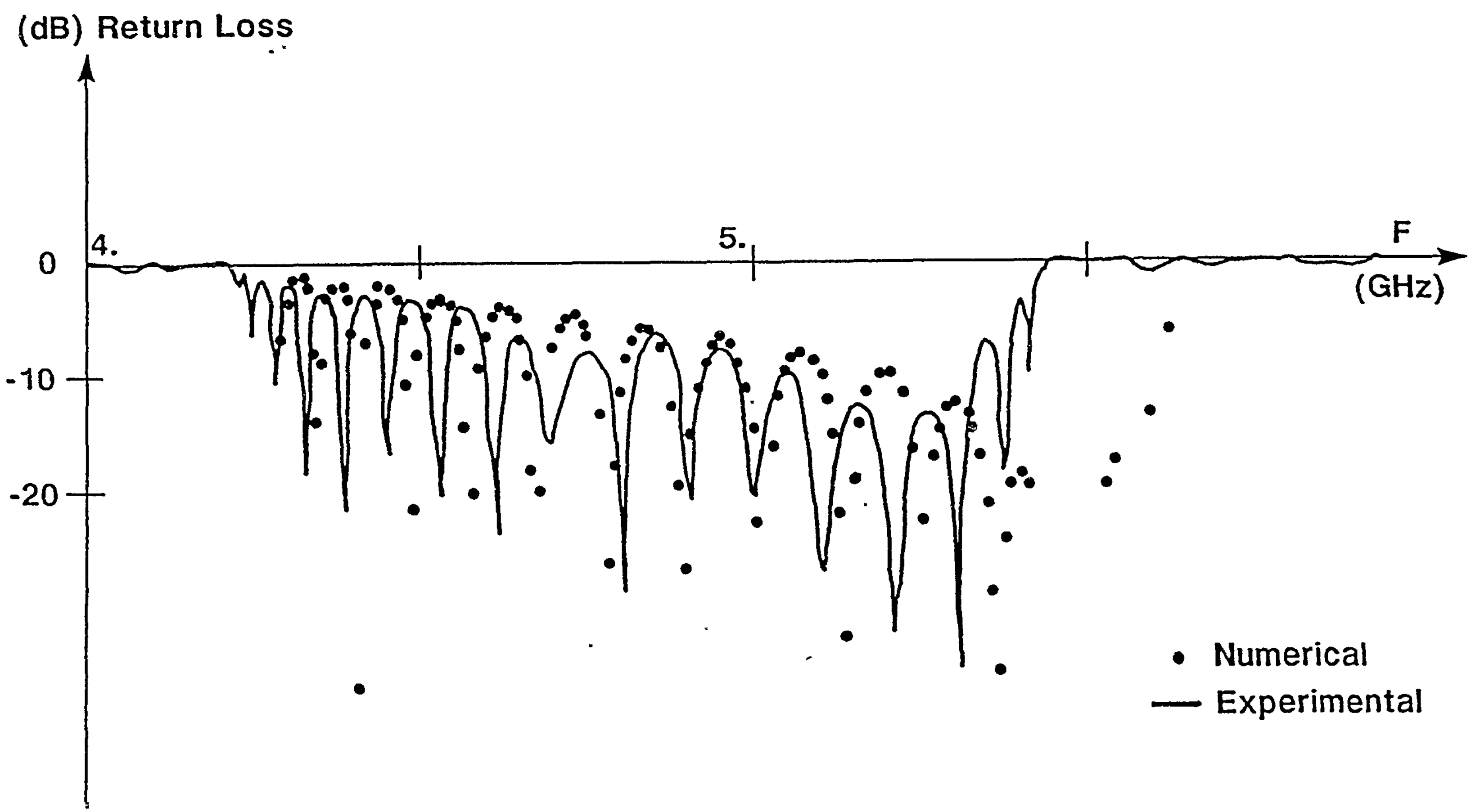
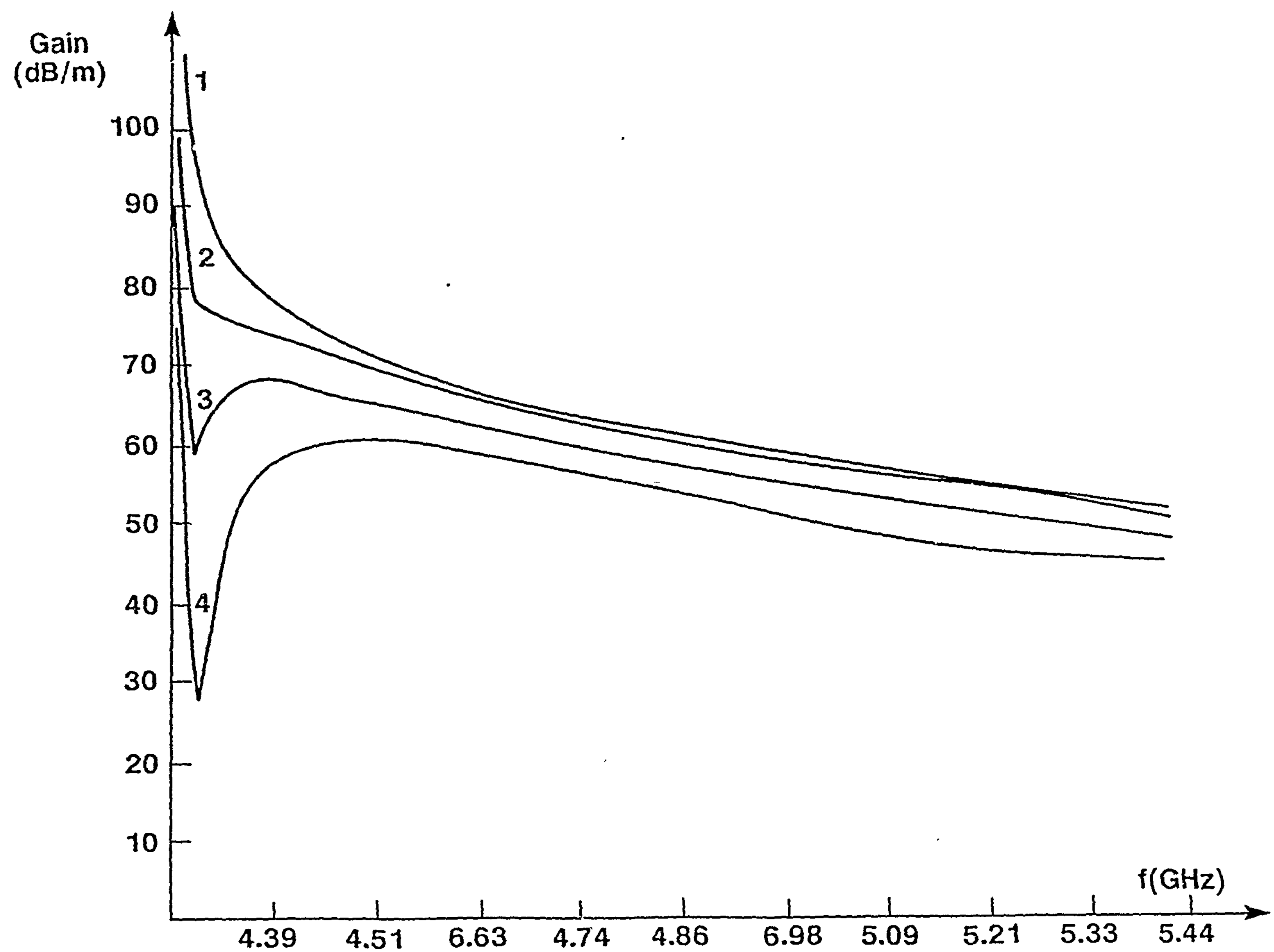
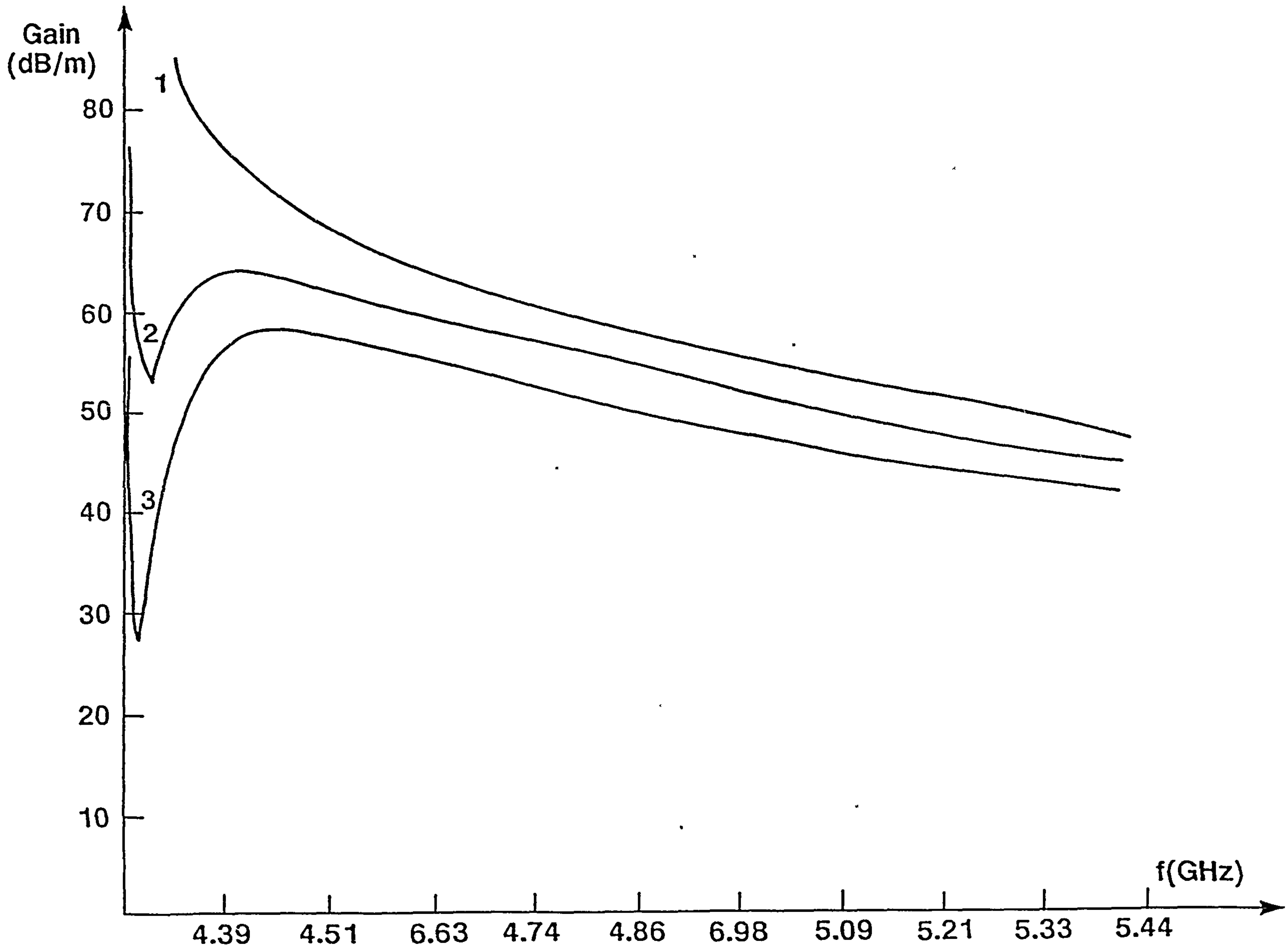


Fig.9 Return loss in dB vs frequency.



<u>Fig.10</u> Linear gain vs frequency for 1 k_b=82, 2 k_b=83, 3 k_b=84, 4 k_b=85



<u>Fig.11</u> Linear gain vs frequency for 1 I_b=5A, 2 I_b=4A, 3 I_b=2A

APPENDIX

Documentation of Computer Programs

1. PROGRAM # 1 , FOR LINEAR ANALYSIS WITH COMPLEX FREQUENCY

Let us begin by introducing the first program which is used for the computation of the linear analysis . The program finds the complex frequency solution of the linear interaction for a given real value of the propagation constant K_z . In this case the equation is a function of the complex frequency F and is of the fourth order . Four distinct roots are determined : two of the roots are real and two are complex conjugates. The complex root with a positive imaginary part is the one of interest : it represents the frequency at which there is gain , determined from the imaginary part .

The program , written in FORTRAN 77 , is under the file name LA2 with an extension { .FOR } for the source file , and { .EXE } for the executable file . Therefore , to run the program on an IBM PC or any compatible computer , you should type LA2 the name of the executable file , followed by pressing the RETURN key .

The following screen comes up :

LINEAR ANALYSIS OF A GYRO-TWA INTERACTION SOLUTION
WITH COMPLEX F GIVEN REAL PROPAGATION CONSTANT K_z

THIS PROGRAM COMPUTES THE SOLUTION OF THE LINEAR
ANALYSIS PROBLEM THAT WILL BE USED FOR THE NON LINEAR
ANALYSIS COMPUTATION. YOU WILL NOW BE ASKED TO ENTER
THE DATA . THEREFORE YOU SHOULD FOLLOW THE PROMPTS .

After reading this , press the RETURN key to continue .

1.1 THE BEAM MODE

The first set of data you will be asked to enter relates to the beam mode . To the question

ENTER THE BEAM VOLTAGE

You should answer by typing the value of the beam voltage in *Kvolts* , only the numerical value is inserted without the units . After pressing the RETURN key , you will be asked :

ENTER THE BEAM CURRENT

As before , you just enter the beam current value in *Amps*, without typing the units. And press RETURN to continue.

1.2 THE WAVEGUIDE MODE

The circuit mode , as described by the equation $K_0^2 = a_4K^4 + a_2K^2 + a_0$ is now going to be computed , and therefore the equation parameters are to be entered in order that the computer process to the computation . However , a choice has to be made here to insert the cut-off wavenumbers , or the cut-off frequencies , or the $a_i's$ factors to be used .

WAVEGUIDE MODE

ENTER:1,IF YOU CHOOSE K_p,and K_m

ENTER:2,IF YOU CHOOSE F_c,and F_m

ENTER:3,IF YOU CHOOSE A_0, A_2,and A_4

$-K_p$ is the lower cut-off wavenumber at $K_z = 0$.

$-K_m$ is the upper cut-off wavenumber at $K_z = \pi/L$.

$-F_c$ is the lower cut-off freqency.

$-F_m$ is the upper cut-off freqency.

$-A_0, A_2$,and A_4 are the coefficients of the polynomial approximation.

Enter your choice of the set of parameters to be used in the computation. For example , if you want to use K_p and K_m ,type 1 followed by pressing the RETURN key .

The computer will respond with the following

ENTER A VALUE FOR K_p

ENTER A VALUE FOR K_m

Press RETURN key , each time you insert data to be processed by the computer . If A_0 ,A_2 ,and A_4 have been choosen , you will be asked to enter values for these coefficients . And the computer will display the following :

ENTER A VALUE FOR A_0

ENTER A VALUE FOR A_2

ENTER A VALUE FOR A_4

Press RETURN key , each time you enter A_i 's values .

Next , you will be asked to enter the periodic length L in meters.

ENTER THE PERIODIC LENGTH L

Note : When you choose A_i's coefficients , you don't have to enter L , because it is computed by the computer.

The computer will display another message asking you to choose one of the following :

CHOOSE ONE OF THE FOLLOWING

CHOOSE A VALUE FOR K_b , ENTER: 1

CHOOSE A VALUE FOR β_z , ENTER: 2

CHOOSE A VALUE FOR $ALFA$, ENTER: 3

CHOOSE BOTH VALUES K_b AND $ALFA$, ENTER: 4

$-K_b$ is the wavenumber related to the electron cyclotron frequency .

$-\beta_z$ is the normalized longitudinal phase velocity $\beta_z = (v_{zo}/C)$.

$Alfa$, a parameter coefficient , is used to determine the value of β_z and β_p . It is a ratio defined su that $\alpha = \beta_p/\beta_z = v_p/v_z$. Where β_p is the normalized parallel

phase velocity over c , $(\beta_p = v_p/c)$, and β_z is the normalized longitudinal phase velocity over c ,$(\beta_z = v_z/c)$.

Type the number corresponding to your choice , followed by RETURN key . For example :

– if you enter 1 , you will see on the screen

CHOOSE A VALUE FOR K_b

enter a value for K_b , then α and β_z are computed .

– if you enter 2 , you will see

CHOOSE A VALUE FOR β_z

enter a value for β_z , then K_b and α are computed .

– if you type 3 , you will see

CHOOSE A VALUE FOR $ALFA$

enter a value for α , then K_b and β_z are computed .

– if you type 4 , you will see

CHOOSE BOTH VALUES K_b AND $ALFA$

enter a value for α and K_b , then only β_z is computed .

Once you have entered all the input data , a display of the LA Menu will be displayed on the screen.

This ends the first part of the program . The computer will now solve the problem and display the results . If the screen moves too fast , use the $CTL-NUM$ keys simultaneously to stop the scrolling , and press RETURN to continue.

After the last result is displayed , the computer will show the following screen :

* THESE ARE THE INPUT DATA INTRODUCED FOR THE COMPUTATION *

1) V_b , 2) I_b , 3) K_p , 4) K_m , 5) L , 6) $Alfa$, 7) K_b, 0) *To continue*

** DO YOU WISH TO CHANGE ANY ONE OF THE INPUT VALUES ? **

IF SO CHOOSE ONE OF THE NUMBER IN FRONT OF EACH DATA , AND PRESS RETURN KEY . OTHERWISE JUST ENTER "0" , AND PRESS RETURN KEY TO CONTINUE .

In front of each input is an integer number . If you wish to change one of the values , type the number placed in front of that variable , and press the Return key. You will return back to the input data entries screen . After inserting the new data the new screen is displayed . To continue the computation just type 0 (zero) .

1.3 UTILITIES

Now the computer asks you what to do with the results : print them , or save them , or make changes . Therefore , the following message helps you choose what to do next .

ENTER ONE OF THE FOLLOWING OPTIONS

ENTER: 1 ,To print or to save the result.

ENTER: 2 ,To change all Input values.

ENTER: 3 ,To change the Wave Guide mode only.

ENTER: 4 ,To change the beam mode only.

ENTER: 5 ,To go to the MENU.

Choose one of the above in the usual way.

1.3.1 PRINT/SAVE MODE

If you want to print tne results type 1 . In that case the computer asks you to select one of the following modes .

SELECT DISPLAY OR PRINTING MODE

ENTER: 1 , display on screen and save result.

ENTER: 2 , use printer (result not saved)

If you choose 1 , you will see the results displayed on the screen and saved in a file. However , If you choose 2 the result will be printed , and not saved . Therefore , you will get the following message :

NOTICE :

When you are asked about UNIT 4.

—Type 4 ,the UNIT number, a file is opened with

a title 4 , and the result is saved . To call

this file type 4 at the keybord .

Therefore, if you enter 4 for the Unit number, you get a screen display of the results, and the output is saved in file 4 that can be retrieved just by typing the file name 4 .

1.3.2 CHANGE OF INPUT DATA

– To change the input values,type 2. The program takes you back to the beginning and ask you to enter new input values for V_b, I_b, and so on .

– To change the waveguide mode type 3. Consequently, the program asks you to change K_p, and K_m, or F_c, and F_m, or A_0, A_2, and A_4; the beam mode and all other variables remain unchanged.

– To change the beam mode type 4. The program asks you to change K_b, or β_z, or $Alfa$, or $Alfa$ and K_b simultaneously ; the waveguide mode and all other variables remain unchanged.

To go back to the Linear Analysis Menu (LA MENU) type 5 . The LA Menu is displayed on the screen.

*** LA MENU ***

WHAT WOULD YOU LIKE TO DO NEXT ?

WOULD YOU LIKE TO PRINT OR REVIEW THE RESULT, ENTER:1

WOULD YOU LIKE TO CHANGE ANY INPUT, ENTER:2

WOULD YOU LIKE TO CHANGE THE BEAM MODE (α, K_b ,β_z) ENTER:3

WOULD YOU LIKE TO EXIT, ENTER:4

Well, if you type 1 you get a review of the results; if you type 2 you make changes on the beam mode, or the waveguide mode, or the periodic length L, etc. If you enter 3 you can only change the beam mode (α , K_b , or β_z). Or if you want to stop and quit the program type 5.

This last message ends up the job of the program # 1, and therefore you may want to perform the computation again with new data input, or just exit. Next is a summary of error messages that you may get .

1.4 ERROR MESSAGES

In this program we have set up warnings , and error messages to help you stay in the program, so that it is possible to correct the mistakes that occured during the computation. However, the computer displays a clear and readable message about what went wrong during the execution, and lets you give another try.

– The following message

" Wrong input , try again "

means that you have entered a number not defined. Try to read carefully and choose one of the given numbers; the number has to be an integer. Otherwise you get an error message such as :

Data format error .

– The message

SQRT of negative argument

is a root square of a negative number which gives an error message . After that press the Return key , the computer will respond with the following

choose a new value for A_2 , or A_4

In this case the message tell you which coefficient to change. Many messages of that type are included in the program to help you change any input that may lead to the computation of an SQRT of negative argument .

– The following error message

Error : Data format error in file user.

Comes up when you are asked to make a choice of an number to be entered in order to select an option for the next step , for example in the message :

Enter : 1 , choose K_b

Enter : 2 , choose β_z

As you see the only options permitted here are : choose K_b or β_z , therefore you have to enter one of the numbers in front of each options . However , You get the error message when you type a character , or a floating point number instead of an integer.

This ends up some of the error messages in the program, however, there is a lot of more messages which are not included here, but you will find easy to correct by using the few examples already stated.

2. PROGRAM # 2 , FOR LINEAR ANALYSIS WITH COMPLEX WAVENUMBER

This program presents the computation of the linear analysis with the wavenumber K complex . It is a replica of program # 1 . Well the program is under the filename LA1 with an extension {.FOR } for the source file, and {.EXE } for the executable file. To run the program type LA1 at the keybord .

First it will ask you to enter the input data one by one until the last one , and then the program is executed. After the work is done, you will be asked about the way to have the output displayed , either to print it, or to save it. If something goes wrong during that time, you will receive an error message , and when you press Return key you will get a message that helps you correct the input variable without quitting the program.

The only differences between the two programs are in the output. At the end, after finishing the work, the result is displayed; however, if you may wish to continue, a menu show you different options to choose what you want to do next. Otherwise, if you want to quit type the number used for exit.

3. PROGRAM # 3 , FOR NON LINEAR ANALYSIS

The non linear analysis is computed by program # 3 which is in the files NLA and SUBNLA ; the source program has the extension .FOR , and the executable

program the extension .EXE . The file SUBNLA is a subroutine file , you must run the two programs together. First you should get the object file for each program by compiling each separately , and then at the linking stage type the following command on the screen : " LINK NLA SUBNLA ; ". After that you will have an executable file under the name NLA. The input data to this program is the result of the linear analysis with complex frequency , which is stored in a data file called DATAFILE2 for convenience . This file is called directly by the program NLA itself. To run the program type NLA , and the following screen comes up :

3.1 USING PROGRAM # 3

```
**NON-LINEAR ANALYSIS OF THE GYRO-TWA INTERACTION**

FIRST OF ALL THE PROGRAM WILL EXECUTE THE COMPUTATION
FOR THE NON LINEAR ANALYSIS . IT IS ALSO USED TO LINK
THE LINEAR ANALYSIS PROGRAM.
THE PROGRAM  NEEDS TO KNOW THE  DIFFERENT PARAME-
TERS ( BEAM AND CIRCUIT ). FOR THAT YOU HAVE A CHOICE
OF EITHER ENTERING  NEW DATA OR USE  PREVIOUSLY COM-
PUTED RESULTS OF THE LINEAR ANALYSIS.
```

After this , a message asks you

```
CHOOSE ONE OF THE FOLLOWING OPTIONS TO START NEXT.

ENTER: 1, FOR NEW PARAMETERS.
ENTER: 2, FOR PREVIOUS LINEAR COMPUTATION.
```

—In the case , there is nc previous computation,

or the data file is empty type 1.

— Otherwise ,type 2.

The first part of the program is the linear analysis . It is the same as program # 1 refer to chapter III. The second part of the program is the non-linear analysis , if you want to use results from a previous linear analysis type 2 , otherwise , type 1 . Whatever the case , at the end of the first part of the program the screen shows a table of the linear analysis results . When you press RETURN again you get :

SELECT ONE OF THE FOLLOWING OPTIONS :

ENTER: 1, TO CONTINUE FOR MORE COMPUTATION.
ENTER: 2, TO STOP FURTHER COMPUTATION , AND
GO BACK TO THE LINEAR ANALYSIS.

When you choose to continue the computation by typing 2 and if the results file is saved , therefore , the results table comes up and you will be asked :

ENTER A NUMBER J FROM THE TABLE OF THE SOLUTION TO
BE USED IN THE FOLLOWING NON LINEAR COMPUTATIONS.

Choose one value for J and the program displays the results up to the maximum value of the electric field . At the end of the computations you will get a display of NLA MENU .

*** NLA MENU ***

WHAT WOULD YOU LIKE TO DO NEXT ?

WOULD YOU LIKE TO REVIEW THE RESULT , ENTER:1

WOULD YOU LIKE TO GO BACK TO LA MENU , ENTER:2

WOULD YOU LIKE TO USE ANOTHER VALUE OF J , ENTER:3

WOULD YOU LIKE TO PRINT THE RESULT , ENTER:4

WOULD YOU LIKE TO EXIT , ENTER:5

As described in the previous section, this message helps you choose the next step; for example if you want to review the non linear analysis results just press 1 . When you press 2 , the program takes you to the linear analysis Menu where you can make changes . In the case you type 3 , a table of the linear analysis is displayed and you are asked to enter a new value for J .

If you press 4 , you will get the print mode .

SELECT A PRINTING OPTION :

ENTER: 1,TO PRINT THE LINEAR ANALYSIS RESULTS.

ENTER: 2,TO PRINT THE NLA RESULTS.

ENTER: 3,TO PRINT BOTH RESULTS.

If you press 5 , you will quit the non linear analysis .

Most of the steps have been explained earlier in program # 1 .

3.2 ERROR MESSAGES

Here we try to present error messages that you may get during the execution process of the program . Most of them have been included in the early chapter. However, some of the errors are particularly to be found within the second part of the non linear analysis.

—An error message that occurs more likely in this program is when you start the non linear program , and you choose to run the program using results previously computed by typing 2 , where no result has been saved. The following error message will be displayed

Error : Data Format Error .

Press the RETURN key , and enter 1 to the following message :

CHOOSE ONE OF THE FOLLOWING OPTIONS TO START NEXT.

ENTER: 1, FOR NEW PARAMETERS.

ENTER: 2, FOR PREVIOUS LINEAR COMPUTATION.

—In the case , there is no previous computation,

or the data file is empty type 1.

– Otherwise ,type 2.

– If the computer displays the following message

** OVERFLOW OPERATION ,DIVISION BY ZERO ,$K_z = 0.0$ **

GO BACK TO THE TABLE AND CHOOSE ANOTHER VALUE FOR J.

An overflow , or a division by zero causes a computation error due to an infinite number. The computer is not provided to carry such a big number. You can correct the error by choosing another value of J , such that K_z is different of zero $\{K_z \neq 0\}$. When you press the Enter key after that message a table of the linear analysis results comes up .

With this final presentation we come to the end of the technical documentation report of the three programs .

4 Graphics

Program LA. (source code: LA.FOR, executable code LA.EXE) combines LA1 and LA2 in the same program, plus it gives you the choice of displaying the results in table form or in graphics form or printing the tables or the graphics.

Note: when using the graphics, the results saved are unformatted, that is, the file contains only numbers whereas, when using the tables, the results saved are formatted, that is, they appear in the form of tables where each number is preceded by the name of the variable it corresponds to.

Warning: To prevent display problems in case an absolute instability exists, the program sets a maximum gain to 400 dB/m. Therefore, this value must be regarded with caution.

For computers other than the AT&T PC 6300 in room N101D where the DOS Graphics utility is loaded automatically, to print a graphics screen, this command must be given to the computer before using the LA program.